

# **Aircraft Battle Damage Repair (ABDR) Strategies and Techniques**

## **INTRODUCTION**

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The overall motivation for this Lecture Series (LS) springs from the following interwoven issues:

- Engagement of NATO has been increasing, albeit in low-intensity unconventional wars
- Recent experience of NATO forces requires maintenance of high combat readiness
- Deployment of air assets is increasingly crucial to warfighter doctrine and tactical success
- Resources for acquisition of new systems have been steadily falling
- Legacy systems, which bring in their wake added set of issues, have been increasing fractions of the assets available to the military commanders
- Damage to air platforms by ground fire is an ever increasing menace
- Temporary repair of aircraft that have suffered battle damage usually needs to be carried out in make-shift bases that are far from home territory under severe time constraint
- Repair is intimately intertwined with certification and safety issues

The LS focuses on repair of damaged air combat platforms including fixed- and rotary-wing aircraft and their major subsystems and components. The experience base for evolution of procedures and processes include cases of aircraft that sustained damage in the brief conflict in Bosnia, and during the ongoing wars in Iraq (Operation Iraqi Freedom-IOF, launched in 2003) and Afghanistan (Operation Enduring Freedom-IEF that was initiated in 2001). Absence of the extensive facilities available at air logistics centers at home is a facet of the latter two wars.

The asymmetric and unconventional warfare or low-level conflicts in Bosnia, Iraq and Afghanistan has been waged by non-state actors and have yielded surprising but valuable lessons for NATO forces. Use of heavy armor has been precluded because of the tactical requirements dictated by highly mountainous terrain or the close proximity to large civilian centers; only lightly armored vehicles have been and are being utilized. As a result, increased reliance on aircraft to project power, for rapid ferrying of troops, or for carrying out medical evacuation in localized theaters have accentuated the roles of fixed- and rotary wing air platforms. Their increased deployment has been met with sometimes effective ground-to-air attacks by the insurgents using small arms and rocket-propelled grenade attacks. In the majority of cases involving damage to aircraft - which number is small - neither the structural integrity nor the electrical system was compromised, however serious degradation occurred, necessitating a systematic approach to try to render the aircraft airworthy and safe to fly, albeit for a short period of time. Again, in the majority of the latter cases, it has been possible to perform the required repair at forward based, maintenance facilities, but there have also been many cases where the aircraft have had to be ferried to home bases that typically are far from the zone of conflict.

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## Aircraft Battle Damage Repair (ABDR) Strategies and Techniques

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During a conflict, a high value air asset – either a fixed- or rotary-wing aircraft – that is non-deployable results in handicapping the military commander, hence urgency is an inevitable issue in the design and fabrication of the BDR, with the focus on flight-safety critical subsystems and components. Repair of the flight-safety critical components and subsystems have to contend with the following risks:

- Detailed design data reside with the Original Equipment Manufacturer (OEM) and is rarely available if the repair is carried out in the field.
- It is axiomatic that the original strength, or durability or functionality can never be equal in a repaired – in contrast to a refurbished – part.
- Absent the ability to perform detailed examinations and tests on the affected parts or components, repair has to be based on estimates and engineering expertise.
- Repair carried out in one location can occasionally cause higher stress, or weakening, or higher voltages at a different location in non-obvious or non-intuitive ways.
- In particular reference to combat aircraft, one has to exercise great care to avoid alteration of the aerodynamic flow field that would result in degraded aerodynamic performance, or diminution of aerodynamic stability characteristics associated with flight maneuvers.

The first order of business in trying to put a battle damaged aircraft back in service is to make an assessment as to which, if any, flight-safety-critical parts or components have been affected and, if so, how badly. This task requires deep knowledge on the part of the engineer who is charged with the responsibility about safety and considerations behind the issuance of the aircraft's airworthiness certificate – knowledge that usually resides with the OEM. Any repair involving a flight-safety-critical part should properly be classified as a Major Repair. What constitutes “major,” as contrasted with “minor,” used to be an issue in commercial aviation in the context of aging aircraft but has since been somewhat clarified. Much the same issue exists within some military regulations.

Always there is a diminution in the strength and durability of the repaired part as compared to the original values. In the case of a properly designed repair the changes will be small but since the original design is based on a number of tests at the coupon-, component-, and assembly-levels the repaired part when it is carried out in the field should be treated as a temporary fix only. More accurate assessment of the impact of the repair should be carried out at the depot or air logistic base.

It is difficult to perform detailed examination on a damaged aircraft. Due to the difficulty and time constraints associated with the conduct of extensive nondestructive inspection (NDI) and metallurgical analysis in the field, a high level of engineering expertise is called for when performing an assessment of the condition of the damaged aircraft. Wing and empennage sections and rotors in helicopters often utilize composite materials. Damage occurring in such components or parts can be latent, meaning the damage or structural degradation may not be externally visible. Hence, NDI equipment will be needed to make a reasonable assessment of the damage. There have been cases when repairs have been carried out on commercial aircraft which have turned out to have unintended, deleterious effects. In one instance, repair of one of the frames of the fuselage caused an increase in the stress at a diametrically opposite location. In another case involving a combat aircraft's landing gear a composite patch was applied only on one side, thus creating asymmetrical stress distribution and induced bending of the part under load, Figure 1 [1]. Hence, care must be exercised to ensure the stress flow remains largely unaffected.

Aerodynamic lifting and control surfaces in modern aircraft are made of composite materials and their repair usually involves use of composite patches that result in a change in the geometrical profile, albeit small. Composite patches are used liberally to patch, thus repair, military aircraft. An example of a composite patch that has been applied on the wing section of a combat aircraft, as shown in Figure 2 [1], illustrates the point. However, the flow field can be affected, in rare cases resulting in separation, thus

altering the lift, drag and moment coefficients and degradation of performance. Particularly in the transonic regime small changes in the profile geometry must be checked carefully; otherwise, effects such as flow separation and limit cycle oscillations may result, which in turn could have a profound effect on the aerodynamic performance, and maneuver and aero-elastic characteristics. In the case of fly-by-wire aircraft, application of a composite repair patch to the tail section might necessitate a redefinition of the parameters in the control laws. Effects like flow separation change the efficiency of the controls, which may require redesign of the control laws (gains and angles). Limit cycle oscillations may be very sensitive to control gains too. In some cases however they can be corrected easily by introducing a small bias to the affected control surface.

The aforementioned considerations have guided the development of the following syllabus for this Lecture Series.

- (a) The epidemiology of aircraft, both fixed- and rotary-wing aircraft that sustained battle damage will be presented. The two presentations will use examples of aircraft damage from the Bosnian conflict, the Operation Iraqi Freedom and Operation Enduring Freedom.
- (b) A primer on composite materials and sandwich structures will be followed by a presentation that covers the aspect of strength and durability loss in damaged composite structures. The above two presentations will be designed to sensitize the military maintenance personnel about the tailoring of material properties to maximize the structure's strength and durability limits and the care that will need to be exercised in retaining those properties when designing BDR.
- (c) The role of NDI in carrying out assessments of ABD, the type of equipment needed, and the attendant logistical issues will next be discussed. The aforementioned presentation will enunciate how NDI is used as a guide to assess BDR, also equipment that is appropriate for field use and the logistical issues that are entailed.
- (d) Current procedures for assessment of battle damage in rotary-wing and fixed-wing aircraft will successively be discussed. Assessment of damage to aircraft in the field and making appropriate decisions on the reparability, making repairs at the lowest repair level possible and evaluating airworthiness of subsequent repairs is critical to maintenance of force projection capability. The above two presentations will visit the procedures used to carry out such assessments and will describe and analyze the echeloned approach of battle damage assessments employed including embedded field maintenance engineers, centralized functional expertise and depot capability at RESET locations. The ABD assessments will encompass primary aircraft structure, secondary structure, engines and fuel systems and electrical wiring systems. The results of the assessment of existing ABD cases will be used to identify areas of improvements necessary for efficient assessment and repair of aircraft systems
- (e) Next, a range of repair types, the selection of the most appropriate repair, and the procedures for conducting the repair will be covered and illustrated by several examples.
- (f) The use of modeling and simulation tools is an important adjunct to performing a proper assessment of ABD, also guide in the design of the repair. The presentation will include a discussion about numerical and other analytical methods, including finite-element techniques, as a means for selection of the appropriate design parameters.

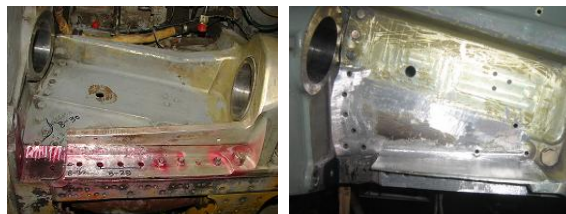
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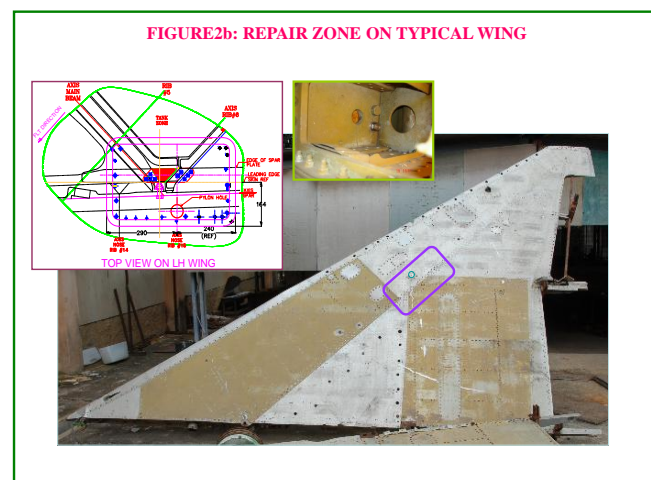
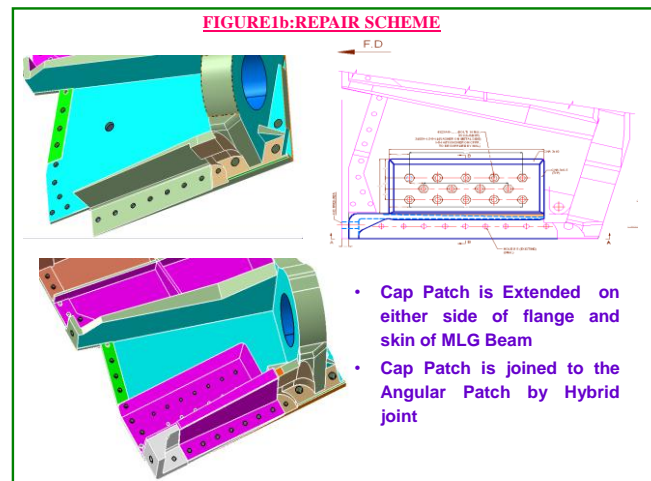
- (g) Design procedures and materials for repair of helicopter airframes, engines and wiring, and design repair of damaged, fixed-wing aircraft will be covered in three back-to-back set of lectures. The presentations will examine existing manuals for select aircraft systems and special ABDR kits that have been recently developed. The ABD assessment results will be discussed in relation to the design process identifying design practices that enhance the aircraft reparability and reduces the vulnerability to damage. Design tools have been developed that allow for quick assessment of field damage by analyzing vulnerable regions of the aircraft in advance with damage limits and repair concepts defined for typical damages. That design tool will be explained and examples provided where efficient ABD repairs have been carried out. The challenges of repairs for new structural member configurations such as high speed machined one-piece frames will be discussed. The challenges of battle damage repair of composite structures will also be addressed. PowerPoint slides will be used to illustrate the difficulties.
- (h) Next, the issues associated with certification and airworthiness of ABDR structures will be presented. The meaning of terms such as Standard Airworthiness Certificate, Technical Standards Order, Special Flight Authorization, Limitations on Waiver, and Temporary Certificate will be explained.
- (i) Following, the methodology of monitoring the structural health (SHM) for the repaired part will be discussed. Monitoring of the repaired part is invariably mandated by the regulator who issues the temporary airworthiness certificate.
- (j) The subject of repair types and procedures will again be visited. Once again, profuse illustrative examples will be presented.

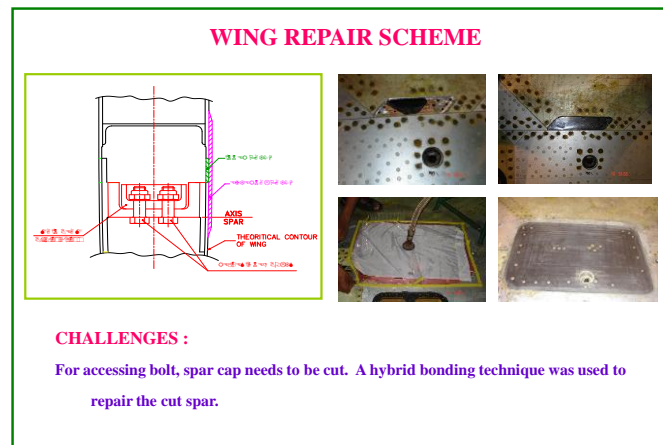
The final session will comprise of a panel discussion among the lecturers and the other attendees. It will be followed by a brief recounting of the lessons learned.

### REPAIR OF CRACKED MLG BEAM OF A COMBAT AIRCRAFT

- MS-315 Main Landing Gear Beam cracked due to stress corrosion cracking
- Two repair schemes proposed by the OEM were for crack length sizes between 66 mm and 180 mm.
- Crack length in this case was found to be 210 mm which is more than the OEM permitted value. Hence repair prescribed in the Repair Manual was inapplicable. 'Crack Patching Technology' was used instead to rehabilitate the trainer aircraft with composites.







## References:

- [1] A.R. Upadhya, private communication.